IPA News Letter
Volume 4, Issue 4 December 2019

Special Contribution

Gross National Safety Index for Natural Disasters (GNS)

Kazuya Itoh[1], Mamoru Kikumoto[2], and Tomofumi Koyama[3]

1 Associate Professor, Urban and Civil Engineering, Tokyo City University
2 Associate Professor, Institute of Urban Innovation, Yokohama National University
3 Associate Professor, Faculty of Societal Safety Sciences, Kansai University

1. Introduction

Japan is one of the countries prone to various natural disasters such as earthquakes, floods, sediment disasters, and volcanos. In recent years, damage due to natural disasters is becoming more and more serious. It has suffered from the devastating damage caused by not only earthquakes but also a succession of localized torrential rains. However, current city's flood protection systems are not enough since the budget and personnel used for disaster prevention and mitigation measures are limited.

Needless to say, establishment of comprehensive disaster prevention and mitigation system is urgent and essential, which is an effective combination of hardware measures such as infrastructure and reinforcement of structures, and software measures such as hazard map development/disclosure and disaster prevention education.

Immediately after the Great East Japan Earthquake, Prof. Kusakabe advocated to create an index of nation-wide safety index, together with Gross Domestic Product (GDP) and Gross National Happiness (GNH), to steadily transform Japan to resilient land and coined GNS. GNS is an abbreviation of Gross National Safety for natural disasters, which is an index expressing quantitative risks for natural disasters. Roger Pulver (2012) showed his keen interest in GNS and stated in his article, "Japan's disaster must prompt a radical rethink of citizen's quality of life", that "Here's my point: The aftermath of the triple calamity in Tohoku has shown that Japan's government and industry have been neglecting the safety and the integrity of the people and the land. A paradigm of growth for the 21st century must consider the kind of scientific methods advocated by Kusakabe.", "The creation of investment security and the husbanding of the land can bring about a merger of the three Gs: GDP, GNS and GNH. Any country or region striving for this would be a magnet for investment and a beacon of hope for the world." Fig. 1 shows the article issued in the Japan Times on March 11, 2012.


The Japan Times

Sunday, March 11, 2012

COUNTERPOINT

Japan's disasters must prompt a radical rethink of citizens' quality of life

Fig. 1. Japan Times on March 11, 2012

In 2012, we have formed a research committee in Japanese Geotechnical Society(JGS) Kanto branch, with an aim of developing a safety index system for natural disasters for policy and decision makers to prioritize prevention and mitigation measures to be implemented. As a result, we published leaflets of GNS2015 and GNS2017 which were presented the concept of the GNS index and the way to calculate the year of 2015 and 2017 version GNS, together with the calculated results of GNS in the prefectural scale. Fig. 2 shows the leaflets of GNS2015 and GNS2017. These leaflets can be downloaded as PDF files from following URL;

GNS2015 (Japanese Version): http://www.jgskantou.sakura.ne.jp/group/pdf/GNS2015.pdf
GNS2015 (English Version): http://www.jgskantou.sakura.ne.jp/group/pdf/GNS2015English.pdf
GNS2017 (Japanese Version): http://www.jgskantou.sakura.ne.jp/group/pdf/GNS2017.pdf

GNS2015 Japanese Ver. | GNS2015 English Ver. | GNS2017 Japanese Ver.

Fig. 2. Leaflets of GNS

In GNS2015 and GNS2017, five natural events were considered including earthquake, tsunami, storm surge, sediment related to disaster events, and volcanic activity. While flood disaster, one of the most serious natural disasters in Japan, was not considered in GNS2015 and GNS2017 because the river basin level is usually needed for the calculation so that it is difficult to consider it in the prefectural scale using statistics data. Moreover, hardware and software measures for disaster prevention and mitigation are usually planned and carried out on various administrative units such as nation, prefecture, and/or municipality. Therefore, the disaster risks also should be evaluated in multi-scale (from national to municipal scales) to increase the effectiveness of investment for disaster prevention and it is also necessary to increase resolution of the damage estimation maps and use consistent statistical data to evaluate natural disaster risks in municipal scale as well.

Furthermore, in Japan, Basic Act on the Advancement of Public and Private Sector Data Utilization was established in 2016, and statistical and geographic information are becoming accessible for free. Statistics and GIS could make it possible not only to provide damage prediction depending on each flood basin but also to consider the most adequate countermeasures by municipality.

In this study, the new calculation methodology using GIS (Geographic Information System) was introduced to evaluate "exposure" of natural disasters more precisely in municipal scale. The newly extended GNS was applied to evaluate natural disaster risks of each municipality in East Japan. Additionally, the "exposure" of flood disasters can be evaluated by superposing damage estimation maps and population distribution using GIS (Mukai et al., 2018).

2. GNS Concept

2.1 Definition of GNS

The natural disaster risk, R can be expressed as the function of hazard H, exposure E, vulnerability V and resilience Re, by the following equation:

$$R = f(H, E, V, \mathrm{Re}) \qquad (1)$$

Here, H×E means "exposure" in a broad sense, which is determined by population distribution, geology and topography in a particular region. Also, V x Re is a value expressing the relation between society and natural disasters. In GNS2015, vulnerability can be expressed by V = V (V, Re). Thus, the natural disaster risk R can be expressed as follows;

$$R = f(H, E, V) \qquad (2).$$

The Eq (2) is a form of function adopted in the GNS calculation. One of the simplest forms may be

$$R = H \times E \times V \qquad (3)$$

The Eq (3) is the actually used equation for GNS2015 and 2017. One of the features of the Eq (3) is that R becomes null

when one of the three parameters are null. Namely, in the cases where no physical event causing hazard occurs (H=0), nor no people lives in the affected area caused by hazard (E=0), society is resilient enough against natural disasters, R

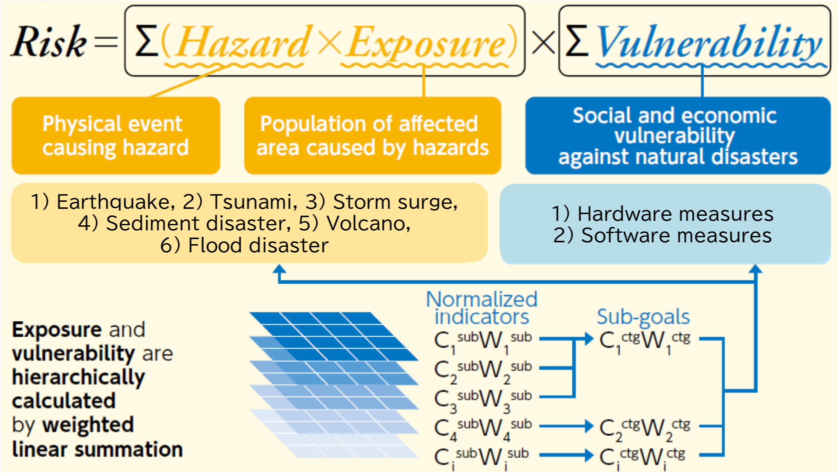


Fig. 3. Concept of GNS

becomes null. In the course of development of GNS2015, the following points are taken into consideration in such a way that the decision and policy maker responsible for budget plan can easily access; 1) Data to be used should be free access for the purpose of continuous updating, 2) Data to be used should be available at the prefectural level to compare one prefecture to another, 3) Prioritizing the items affecting for improving natural disaster measures and the items with higher propriety should be selected and 4) The values of hazard, exposure and vulnerability should be hierarchically calculated by weighted linear summation as shown in Fig. 3.

2.2 Exposure

As for "exposure", the following 6 natural disasters are considered; (a) earthquake, (b) tsunami, (c) high tide (storm surge), (d) sediment disaster, (e) volcanic disaster, and (f) newly added flood disaster. In this study, in order to precisely evaluate the "exposure" of natural disasters except for earthquake and volcanic disaster in municipal scale, the population distribution exposed by each natural disaster was calculated using GIS software (by superimposing population data in municipal scale and estimation of damage caused by each disaster) (Mukai et al., 2018). While, the "exposure" of earthquake and volcanic disaster was evaluated in the prefectural scale due to the difference in the time scale and the frequency of occurrence. The frequency coefficient, which varies from 0 to 1, was defined by the following equation,

$$F_i = 1 - \exp(-N_i / \bar{N}) \qquad (4)$$

The Eq (4) is used and this frequency coefficient is expressed as H in Eq (3). In Eq (4), Ni is the cumulative number of disaster occurrences in each prefecture, and $\bar{N}$ is the average number of occurrences in 47 prefectures in Japan.

For the earthquakes, a further grouping is required. There are two types of earthquake; inter-plate earthquakes and earthquakes located directly above the focus. In GNS2015 and 2017, the data were normalized by different methods for each type of earthquake. Exposure Sub-goals are determined by 6 Normalized indictors based on 10 different Original data bases (Abe, 2006; Active faults research group, 1991; Arakawa et al., 1961; Cabinet Office, Government of Japan, 2015a; Geospatial Information Authority of Japan, 2015; Japan Meteorological Agency, 2015; Jiban-net, 2015; Ministry of Internal Affairs and Communications, 2015c; Miyazaki, 1956; Nakata and Imaizumi, 2002; Japan Meteorological Agency and Volcanological Society of Japan, 2003; National Research Institute for Earth Science and Disaster Prevention, 2015; National Land Information Division, National Spatial Planning and Regional Policy Bureau, MLIT, 2015; Statistical Information Institute Consulting and Analysis, 2015; The Headquarters for Earthquake Research Promotion, 2015).

For the inter-plate earthquakes, J-SHIS (Japan Seismic Hazard Information Station) Map prepared by National Research Institute for Earth Science and Disaster Prevention (2015) is utilized. The Map provides the distribution of population (population seismically exposed; PSE) in the areas, of which seismic intensity exceeds a certain value, for a given focus and a given magnitude of earthquake. In GNS2015 and GNS2017 calculations, equal or over the seismic intensity of 6 caused by the above 13 earthquakes was taken as "Exposure" for the inter-plate earthquakes. For the earthquakes located directly above the focus, extended lengths of active faults are used, and the extended lengths are divided by the total area of the prefecture, which is equivalent to a density of active faults. Since a clear separation of exposure calculated due to these two types of earthquake is not straightforward, the average value of the two exposures is used in the calculation.

For tsunami, “Tsunami Inundation Prediction” map provided by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is used to evaluate the population in the affected areas. For storm surges (high tide), the area 3 meters below the sea level is considered as the affected area and population in the affected area is calculated.

For sediment disasters, “sediment disaster hazard points” in the national land numerical information download service provided by MLIT are used to calculate the population in the affected area.

For volcanic disasters, the data are used in the chronological table of volcanic disaster from the year of 1600 onwards published by the Meteorological Agency (2003). The exposure of volcanic disasters is multiplying the percentage of people living in the volcanic areas and the frequency coefficient.

For flood, which is newly introduced, “Inundation Prediction” map provided by MLIT is used to evaluate and the population in the affected area with over 2 meters in inundation depth is considered. For each natural disaster, the exposure (E) can be calculated accurately by superimposing the above-mentioned affected area by natural disasters and the population distribution obtained from the portal site of Japanese Government Statistics (so-called e-Stat) provide by Statistics Bureau of Japan by using GIS. The national census is taken every five years and the population distribution data are also updated every five years.

2.3 Vulnerability

For vulnerability assessment, available data are categorized into two; hardware measures and software measures as an ordinary accepted classification. Hardware measures means physical disaster prevention methods such as aseismic methods of structures and upgrading methods of aged infrastructures to mitigate against natural disasters. Hardware measures indicators are classified into a group of sub-indicators named a sub-category. Four sub-categories are selected:(1) house, public facilities, (2) utility lines such as gas, water, sewage network (3) infrastructures (4) information, telecommunication. In the process of calculation of hardware measures indictors, sub-categories are calculated from 14 different data bases and then sub-categories are multiplied by weighted coefficients, leading to the values of these subcategories.

Software measures means measures other than hardware measures, including a social system of conducting frequent disaster education, stocking food for emergency and preparing manuals at the time of disasters. Four sub-categories are selected. (1) relief goods, food stock, (2) medical services, (3) economy and population structure, (4) insurance, (5) regulations/autonomy. Similar to that in the calculation process of hardware measures index, sub-indicators are obtained from a cluster of 22 database, and subcategories are multiplied by weighted coefficients. Finally, both hardware and software measures indicators are obtained by multiplying the weighted coefficient (see Table 1).

Table 1 Source data, normalized indicators, sub-goals, and weighting coefficients for the calculation of GNS

Original data	Normalized indicators	Weight Wi	Sub-goals	Weight wi	Sub-goals	Weight wi	Risk compo	Risk index
J-SHIS Map (Disaster affected people)	Inter-plate earthquake	1/2	Earthquake	1/6	-	-	Exposure	GNS
Total length of active faults [km]	Epicentral earthquake	1/2						
Tsunami inundation supposition	Tsunami	1.0	Tsunami	1/6				
Tsunami area population rate of altitude less than 3m [%]								
Number of storm surge [times]	Storm surge	1.0	Storm surge	1/6				
Population rate of altitude less than 3m [%]								
Sediment disaster hazard points	Sediment disaster	1.0	Sediment disaster	1/6				
Sediment disaster area population rate [%]								
Number of volcanic disasters	Volcano disaster	1.0	Volcano disaster	1/6				
Population rate in volcanic area [%]								
flood assumption area	Flood disaster	1.0	Flood disaster	1/6				
flood area population rate of altitude less than 2m [%]								
Rate of earthquake resistant private building [%]	Rate of earthquake resistance of buildings	1/3	Buildings	1/4	Hardware	1/2	Vulnerability	
Rate of earthquake resistant public building [%]								
Rate of non-fireproof wooden houses [%]	Rate of non-fireproof houses	1/3						
Rate of damaged buildings [%]	Rate of damaged buildings	1/3						
Rate of earthquake resistant main pipelines [%]	Rate of earthquake resistance of water supply and drainage facilities	1/2	Lifelines	1/4				
Rate of earthquake resistant purification plants [%]								
Rate of earthquake resistant service reservoirs [%]								
Rate of decrepit pipeline (over 40 years) [%]	Percentage of decrepit pipeline	1/2						
Total length of road [km]	Road density index	1/2	Infrastructures	1/4				
Repair rate of bridges [%]	Repair rate of bridges	1/2						
Rate of development of broadcast communication equipment system [%]	Rate of development of radio communication facilities for disaster prevention	1/2	Information, networks	1/4				
Rate of development of portable broadcast communication system [%]								
Rate of development of J-Alert system [%]	Rate of development of J-Alert system	1/2						
Rate of development of J-Alert automatic system [%]								
Number of stockpiling hardtacks [meals]	Stockpiling foods	1/5	Emergency stockpile	0.225	Software	1/2		
Number of stockpiling instant noodles								
Amount of stockpiling rice [kg]								
Number of stockpiling canned staple foods								
Number of stockpiling side dishes								
Amount of stockpiling water [l]	Stockpiling water	1/5						
Number of stockpiling blankets	Stockpiling blankets	1/5						
Number of supermarket store	Supermarket store index	1/5						
Number of convenience store	Convenience store index	1/5						
Number of physicians	Number of Physicians per 100,000 population	1/2	Medical services	0.225				
Number of hospital beds	Number of Hospital beds per 100,000 population	1/2						
Financial capability index	Financial capability index	1/4	Economy and population	0.225				
Gini coefficient	Gini coefficient	1/4						
Old-age index [%]	Old-age index	1/4						
Rate of persons who received public aid [%]	Rate of persons who received public aid	1/4						
Rate of participation in earthquake insurance [%]	Rate of participation in earthquake insurance	1	Insurance	0.10				
Number of dangerous sites subject to sediment disaster	Rate of specification of sediment disaster prone areas	1/3	Regulations and governance	0.225				
Number of sediment disaster prone areas								
Number of municipals publishing hazard maps for tsunami disaster	Rate of publication of hazard maps	1/3						
Number of municipals publishing hazard maps for floods disaster								
Number of municipals publishing hazard maps for sediment disaster								
Rate of households covered by voluntary disaster prevention organization [%]	Coverage rate for the voluntary disaster prevention organization	1/3						

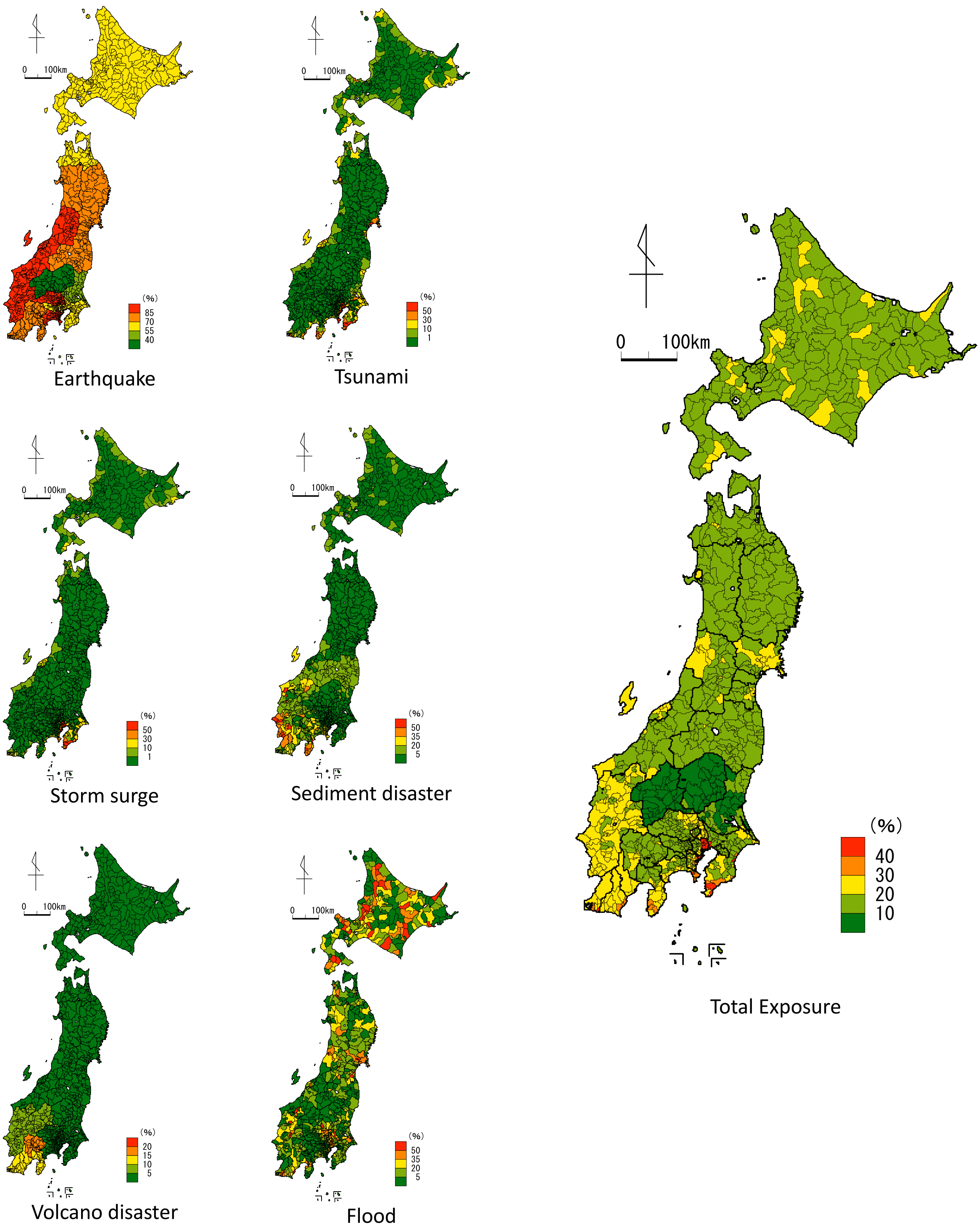


Fig. 4. Exposure

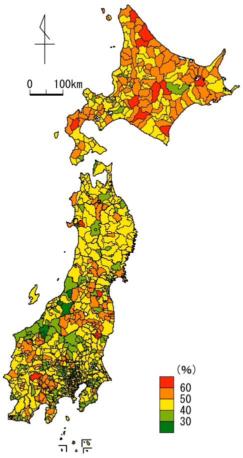
3. Natural disaster risks at East Japan area evaluated by GNS

3.1 Exposure

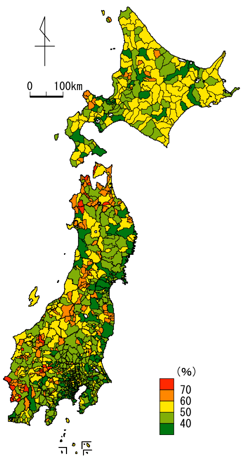
Fig. 4 shows the exposures of natural disasters in municipal scale in East Japan. The exposures of tsunami and storm surge are larger in the coast coastal areas of Chiba, Tokyo, Kanagawa, Shizuoka and Miyagi prefectures. The exposure of sediment disaster is larger near in mountainous areas of Kanagawa, Shizuoka, Nagano, and Niigata prefectures. As for flood, there are some municipalities with large flood exposure along first-class rivers in Saitama, Tokyo, Shizuoka, Nagano, Miyagi, and Hokkaido prefectures. The final summary of exposures is shown below. The three prefectures of Gunma, Tochigi, and Ibaraki have low exposures, and the exposures in coastal areas such as Tokyo, Chiba, Kanagawa, and Shizuoka tend to be high.

3.2 Vulnerability

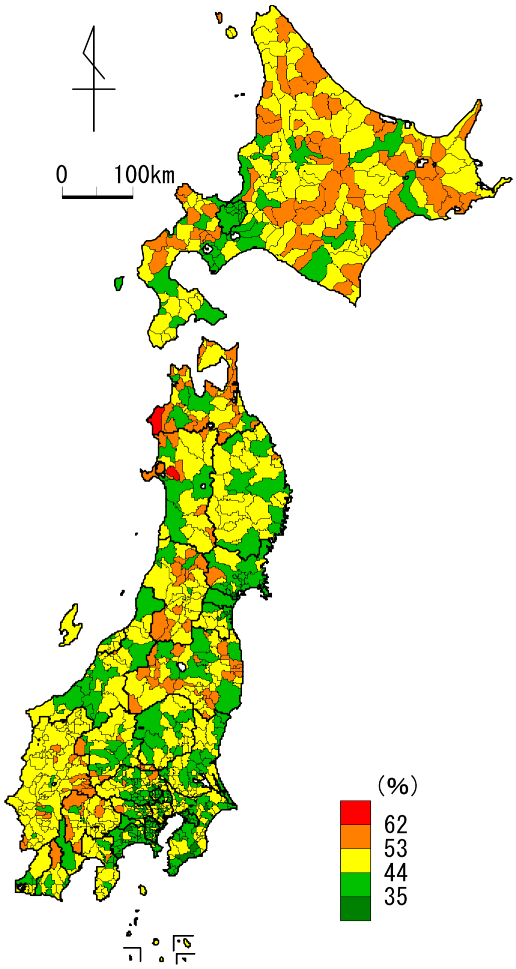
Fig. 5 shows the vulnerability obtained from the sum of hardware and software measures. Both vulnerabilities of hardware and software are not different in the prefectural scale but some differences are seen depending on municipalities, which are expressed with mosaic patterns.



Vulnerability related to hardware measures



Vulnerability related to software measures



Total vulnerability

Fig. 5. Vulnerability

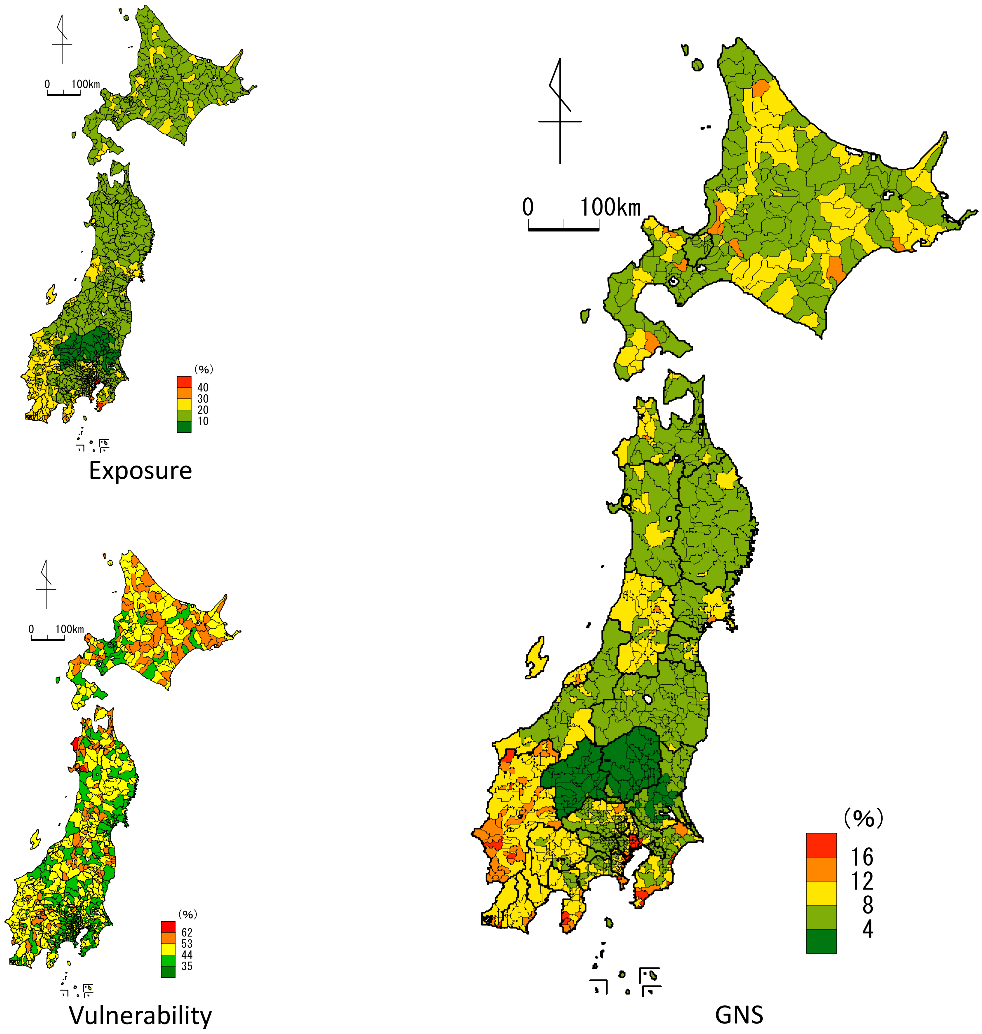


Fig. 6. GNS

3.3 GNS

Fig. 6 shows exposure, vulnerability, and GNS. The trend of GNS shows a tendency similar to that of exposure, which means that exposure has a great influence on GNS. GNS can indicate natural disaster hotspots in municipal scale.

4. Conclusions

In this study, the new calculation methodology using GIS (Geographic Information System) was introduced to evaluate exposure of natural disasters more precisely in municipal scale. The newly extended GNS was applied to evaluate natural disaster risks of each municipality in East Japan. Additionally, the exposure of flood disaster can be evaluated by superposing damage estimation maps and population distribution using GIS.

5. Acknowledgements

The authors are grateful to Kosuke Mukai of Nippon Koei (former Kansai University), Hideyuki Fukushima of Shizuoka Prefecture (former Tokyo City University), Sawa Kajitani of Kansai University and Reo Toma of Tokyo City University for assistance with the GNS calculation. The research was supported by JSPS Department Research Project JP16H03156, “Establishment of vulnerability assessment for Gross National Safety for Natural Disasters (GNS) construction and reflection in disaster prevention strategy” (Representative: Kazuya ITOH).

6. Reference

Abe, K. (2006) Size of tsunamis around Japan for 1498-2006, wwweic.eri.u-tokyo.ac.jp/tsunamiMt.html (accessed 2015-12-09).

Active Faults Research Group (1991) Active faults in Japan, University of Tokyo Press, p. 437.

Arakawa, T., Ito, Y. and Ishida, C. (1961) The History of storm surge in Japan, Meteorological Research Institute.

Cabinet Office, Government of Japan (2015a) White Paper on Disaster Management (Damage costs), www.bousai.go.jp/kaigirep/hakusho/index.html (accessed 2015-12-09).

Geospatial Information Authority of Japan (2015) Active Fault Map in Urban Area, www.gsi.go.jp/bousaichiri/active_fault.html (accessed 2015-12-09).

Japan Meteorological Agency (2015) Summary of Tables explaining the JMA Seismic Intensity Scale, www.jma.go.jp/jma/en/Activities/intsummary.pdf (accessed 2015-12-09).

Jiban-net (2015) Jiban Anshin Map (Disaster prevention map) www.jibanmap.jp/map/main.php (accessed 2015-12-09).

Ministry of Internal Affairs and Communications (2015c) The earth and sand disaster prevention, www.soumu.go.jp/menu_news/ s-news/000066869.html (accessed 2015-12-09).

Miyazaki, M. (1956) Japan's coast menaced by storm surge damage, Proc. 3rd conference on coastal engineering, pp. 1-8 (in Japanese).

Mukai, Y., Koyama, T., Itoh, K., and Kikumoto, M (2018) Examination of natural disaster exposure between municipalities in Osaka prefecture by extended GNS using geospatial information, The 73rd Annual conference of Japan Society of Civil Engineers, pp. 279-280.

Nakata,T. and Imaizumi, T. (2002) Detail Active Faults of Japan, University of Tokyo Press, p. 59, DVD.

O. Kusakabe, M. Kikumoto, K. Shimono, K. Itoh, H. Inagaki, S. Ohsato, K. Watanabe：Development of Gross National Safety Index for Natural Disasters, Geotechnical Engineering Journal of the SEAGS & AGSSEA, Vol. 48, No. 1, 90-101, 2017/04.

Japan Meteorological Agency and Volcanological Society of Japan (2003) National Catalogue of the Active Volcanoes Japan, www.data.jma.go.jp/svd/vois/data/tokyo/STOCK/souran_eng/menu.htm (accessed 2015-12-09).

National Research Institute for Earth Science and Disaster Prevention (2015) J-SHIS, Japan Seismic Hazard Information Station, www.j-shis.bosai.go.jp/en/ (accessed 2015-12-09).

National Land Information Division, National Spatial Planning and Regional Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism (2015) National Land Numerical Information download service, nlftp.mlit.go.jp/ksj-e/index.html (accessed 2015-12-09).

Roger Pulvers (2012) Japans's disasters must prompt a radical rethink of citizens' quality of life, The Japan Times, www.japantimes.co.jp/opinion/2012/03/11/commentary/japans-disasters-must-prompt-a-radical-rethink-of-citizens-quality-of-life (accessed 2015-10-2).

Statistical Information Institute Consulting and Analysis (2015) Demographic statistics according to the topography and analysis (in Japanese).

The Headquarters for Earthquake Research Promotion (2015) www.jishin.go.jp/main/index-e.html (accessed 2015-12-09).

◆ A brief CV of Dr. Kazuya Itoh

Kazuya Itoh graduated from Musashi Institute of Technology with Bachelor and Master degrees in the field of Civil Engineering in 1998 and 2000, respectively. He obtained his Ph. D degree from Tokyo Institute of Technology in the field of Civil Engineering in 2003. After his Ph. D, he worked in National Institute of Occupational Safety and Health, Japan (JNIOSH) then move to Tokyo City University from April, 2015. He is currently Associate Professor in Tokyo City University. His research field is physical modelling in geotechnical engineering, and he involves many civil engineering projects such as prevention and mitigation of geo-disasters, labour accident caused by geotechnical field etc.

◆ A brief CV of Dr. Mamoru Kikumoto

Mamoru Kikumoto graduated from Kyoto University with Bachelor's, Master's, and Ph. D degrees in the field of Civil Engineering in 2000, 2002, and 2005, respectively. Afterward, he worked for three years as a JSPS postdoctoral fellow and for four years as an Assistant Professor at Nagoya Institute of Technology. Then, he moved to his current institution, Yokohama National University, to be an Associate Professor. His main research field is the constitutive modeling of geomaterials.

◆ A brief CV of Dr. Tomofumi Koyama

Tomofumi Koyama graduated from Kyoto University with Bachelor and Master degrees in the field of Civil Engineering in 1999 and 2001, respectively. He also obtained his Ph. D degree from Royal Institute of Technology, Sweden (KTH) in the field of land and water resources sciences in 2007. After obtaining his Ph. D, he worked in Kyoto University as Assistant Professor until the end of March, 2014 and move to Kansai University from April, 2014. He is currently Associate Professor in Kansai University. His research field is rock mechanics and he involves many civil engineering projects such as prevention and mitigation of geo-disasters, geological disposal of high-level nuclear waste, maintenance of aged infrastructures etc.